DOCKET FILE COPY ORIGINAL

AT&T

Cathleen A. Massey
Vice President - External Affairs

AT&T Wireless Services, Inc
Fourth Floor
1150 Connecticut Ave NW
Washington, DC 20036
202 223-9222
FAX 202 223-9095
PORTABLE 202 957-7451

March 5, 1996

William F. Caton
Acting Secretary
Federal Communications Commission
1919 M Street, N.W.
Mail Stop Code 1170
Washington, D.C. 20544

RE: Ex Parte Presentations
1) Interconnection between Local Exchange Carriers and Commercial Mobile Service Providers -- CC Docket No. 95-185
2) Amendment of the Commission's Rules to Permit Flexible Offerings In CMRS -- WT Docket No. 96-6; and
3) Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation -- ET Docket 93-62

Dear Mr. Caton:

Pursuant to the requirements of Sections 1.1200 et seq. of the Commission's Rules, you are hereby notified that on behalf of AT&T Corp. and AT&T Wireless Services, Inc., the attached materials were provided to Suzanne Toller of Commissioner Rachelle Chong's office.

Should there be any questions regarding this matter, please contact me.

Sincerely,

Cathleen A. Massey

Cathleen A. Massey

cc: Suzanne Toller

Recycled Paper

CMRS-LEC Interconnection

- This rulemaking proceeding is a critical part of the Commission's mission to eliminate barriers to wireless competition to the local loop. As the Commission has noted, "changes in compensation arrangements are necessary if CMRS services "are to begin to compete directly against LEC wireline services."

- AT&T supports the Commission's tentative conclusion to adopt bill and keep as an interim mechanism to govern CMRS - LEC interconnection. To recognize the mutual benefits inherent the LEC-CMRS interconnection model, the Commission should broaden the scope of its bill and keep proposal to apply to each carriers' entire termination service -- i.e., extend bill and keep to cover access, switching and transport between the end user and the tandem.

- Bill and keep is an appropriate interim compensation measure because the implicit charges for traffic termination between CMRS and LEC networks provide a reasonable proxy to the actual incremental costs:

  -- While today more CMRS traffic may terminate on the LEC network then vice versa, it is also the case that it costs CMRS providers more to terminate traffic on CMRS networks then it costs LECs to terminate traffic of their networks. In these circumstances, bill and keep is a reasonable proxy on an interim basis for TSLRIC.

  -- The Commission can expect that traffic flows will become essentially even after bill and keep is adopted, since bill and keep removes a significant barrier to co-equal status of CMRS providers and LECs.

  -- In addition, bill and keep is appropriate because the likely real incremental costs incurred by LECs to terminate a CMRS originated call is de minimis.

- As a long-term arrangement, the Commission should require LECs to set interconnection rates for CMRS providers at total service, long-run incremental cost ("TSLRIC"). TSLRIC emulates that pricing that would occur if the local telephone market was competitive and it prevents LECs from engaging in a "price squeeze" by charging supra-competitive access rates.

- The FCC should exercise its plenary jurisdiction over interconnection and require LECs and CMRS providers to comply with specific federal regulations for both interstate and intrastate traffic because:

  -- a uniform national policy on LEC-CMRS interconnection, including compensation, is essential to ensure the growth and development of wireless services;

  -- Congress confirmed the FCC's plenary jurisdiction over CMRS-LEC interconnection when it enacted Section 332(c) in 1993;

  -- Even apart for 332(c), the inseverable nature of interstate and intrastate wireless transmissions justifies preemption of intrastate interconnection rates; and

  -- Nothing in the Telecommunications Act of 1996 disturbs the Commission's plenary authority over these matters.

CMRS Flexibility

- AT&T strongly supports the Commission's proposal to clarify that CMRS providers may offer primarily fixed services on their wireless spectrum. This action will:

  -- allow wireless providers to make the most efficient use of their facilities
  -- enhance the options available to customers
  -- allow the development of competition in the local exchange marketplace.

- The Commission should not limit the types of fixed services that CMRS providers may provide since this could result in artificial regulatory distinctions that would not serve the public interest.

- Until and unless wireless networks incorporating fixed services have actually become a substitute for wireline local loop service, the Commission should continue to regulate all wireless services provided by CMRS licensees as CMRS.

- It is important for the Commission to quickly issue an order clarifying the ability of CMRS providers to provide primarily fixed services.

RF Standard

- Pursuant to Section 704(a) of the 1996 Act, no State may regulate the placement, construction and modification of wireless service facilities on the basis of the environmental effects of RF emissions if the facilities comply with FCC regulations on such emissions. Pursuant to Section 704(b), the FCC is instructed to complete action in its open RF standards docket item (ET 93-62) by August 6, 1996.

- The Conference Report on this provision makes clear that Congress intended Section 704(a) to prevent State or local governments from basing their land use regulations and decisions "directly or indirectly" on CMRS RF emissions. Congress intended the FCC to be the sole regulator of CMRS RF emissions. This would preclude regulations designed to ensure compliance with Federal standards which are not otherwise required by the Federal rules such as periodic monitoring, fencing, signage, power limitations, etc.

- The FCC should move quickly to adopt ANSI/IEEE C95.1-1992 as the exclusive Federal RF standard.

  -- the ANSI standard is widely accepted by experts in government (FDA, OSHA, DOD), academia and industry. The standard was produced by a 120 member committee from over 14 scientific disciplines through a consensus process open to public comment.

  -- The FCC has already adopted the ANSI standard for PCS services. *See* 47 C.F.R. § 24.52. Many cellular carriers are voluntarily complying with the ANSI standard to ensure safe facilities.

  -- The ANSI standard includes implementation guidance and provides for ongoing interpretation through a consensus process.

- The only other standard being discussed, the 1986 NCRP standard, does not reflect current scientific literature, was not the product of a broad-based consensus process, and contains no implementation guidance or ongoing interpretation program. The NCRP standard also includes a scientifically insupportable limit on low frequency modulation that could imperil emerging wireless digital technologies.

ANSI on athermal effects

321 papers selected from the archival literature (Appendix A) was reviewed for biological, engineering, and statistical validity (see 6.3). It was agreed that only peer-reviewed reports of studies at SAR ≤ 10 W/kg, which had received favorable engineering and biological validation, should be considered relevant to the assessment of risk from exposure to electromagnetic fields in the resonance range. The literature review was followed by extensive deliberations of the Risk Assessment Working Group that was charged to reach agreement on an SAR at which potentially-deleterious health effects are likely to occur in human beings. A majority of the Risk Assessment Working Group agreed that the literature is still supportive of the 4 W/kg criterion. Further, the ANSI 1982 safety factor of 10 was reaffirmed by Subcommittee IV, yielding an SAR of 0.4 W/kg as the working basis for the MPE. The question then arose of the need for two tiers of MPE (as adopted by NCRP, 1986 [B52]) to distinguish occupational vs. general public exposures.

To some, it would appear attractive and logical to apply a larger, or different, safety factor to arrive at the guide for the general public. Supportive arguments claim subgroups of greater sensitivity (infants, the aged, the ill and disabled), potentially greater exposure durations (24-hr/day vs. 8-hr/day), adverse environmental conditions (excessive heat and/or humidity), voluntary vs. involuntary exposure, and psychological/emotional factors that can range from anxiety to ignorance. Non-thermal effects, such as efflux of calcium ions from brain tissues, are also mentioned as potential health hazards. The members of Subcommittee IV believe the recommended exposure levels should be safe for all, and submit as support for this conclusion the observation that no reliable scientific data exist indicating that:

(1) Certain subgroups of the population are more at risk than others
(2) Exposure duration at ANSI C95.1-1982 levels is a significant risk,
(3) Damage from exposure to electromagnetic fields is cumulative, or
(4) Nonthermal (other than shock) or modulation-specific sequelae of exposure may be meaningfully related to human health.

No verified reports exist of injury to human beings or of adverse effects on the health of human beings who have been exposed to electromagnetic fields within the limits of frequency and SAR specified by previous ANSI standards, including ANSI C95.1-1982 [B1]. In the promulgation of revised guidelines, the responsibility of the current Subcommittee IV is adherence to the scientific base of data in the determination of exposure levels that will be safe not only for personnel in the working environment, but also for the public at large. The important distinction is not the population type, but the nature of the exposure environment. When exposure is in a controlled environment, the scientifically-derived exposure limits apply. When exposure is in an uncontrolled environment, however, an extra safety factor is applied under certain conditions; these include, but are not limited to, the following:

(1) Exposure in the resonant frequency range, and
(2) Low-frequency exposure to electric fields where exposure is penetrating or complicated by associated hazards like RF shocks or burns induced by metal contacts.

As defined earlier, uncontrolled environments include the domicile and most places where the infirm, the aged, and children are likely to be. It also includes the work environment where employees are not specifically involved in the operation or use of equipment that does or may radiate significant electromagnetic energy and where there are no expectations that the exposure levels may exceed those shown in Table 2. On the other hand, controlled environments may involve exposure of the general public as well as occupational personnel, e.g., in passing through areas such as an observation platform near a transmitting tower where analyses show the exposure may be above that shown in Table 2 but is below that in Table 1. Other exposure conditions include that of the radio amateur who voluntarily and knowledgeably operates in a controlled RF environment.

At frequencies below 3 MHz, the MPEs, in terms of magnetic fields, have been relaxed to more reasonably correspond to whole-body SAR limits. On the other hand, the MPEs, in terms of E field, continue to be capped below 3 MHz in order to limit the possibility of reactions (shocks or burns) at the surface of the body that might occur in E fields of high strength, especially under conditions of spatial and temporal field concentration.

In this standard, there are extensive modifications of the averaging time for determining permissible exposure. At the upper frequencies, these rules agree with soundly-based averaging times derived from optical considerations. At the lower frequencies, new rules on induced currents have been introduced to prevent RF shock or burn upon grasping contact with an object in an RF environment. These rules supplement the limits on E and H field exposure.

This standard is thus an extension of ANSI C95.1-1982 [B1], and incorporates many refinements that will serve to make the MPEs more useful in a greater variety of exposure situations. There remain areas, however, which the standard does not cover, e.g., the possible exposure of the body to transient spark-discharge phenomena upon touching a large conducting object in an RF environment. Future research may provide the data base from which quantitative rules for preventing adverse effects from such discharges can be derived.

Research on the effects of chronic exposure and speculations on the biological significance of nonthermal interactions have not yet resulted in any meaningful basis for alteration of the standard. It remains to be seen what future research may produce for consideration at the time of the next revision of this standard.

6.1 Recognition of Whole-Body Resonance. As is true of ANSI C95.1-1982 [B1], the MPE in this standard is based on recommendations of field strengths or of plane-wave-equivalent power densities of incident fields, but these limits are based on well established findings that the body, as a whole, exhibits frequency-dependent rates of absorbing electromagnetic energy [B6, B20, B21, B25]. Whole-body-averaged SARs approach maximal values when the long axis of a body is parallel to the E-field vector and is four tenths of a wavelength of the incident field. Maximal absorption occurs at a frequency near 70 MHz for Standard Man (height = 175 cm) and results in an approximate seven-fold increase of absorption relative to that in a 2450 MHz field [B22, B27]. In consideration of this dependency, recommended MPEs of field strength have been reduced across the range of frequencies in which human bodies from infants to large adults exhibit whole-body resonance. Above 6 GHz, the absorption is quasi-optical and body resonance considerations do not apply.

6.2 Incorporation of Dosimetry. Dosimetry is the fundamental process of measuring physical quantities of energy or substances that are imparted to an absorbing body [B40, B41]. In 1972, The National Council on Radiation Protection and Measurements (NCRP) convened Scientific Committee 39 to deliberate and recommend dosimetric quantities and units applicable to electromagnetic fields [B51]. In keeping with the NCRP recommendations, in 1982 the ANSI C95 Subcommittee IV adopted the unit-mass, time-averaged rate of electromagnetic energy absorption, as specified in units of watts per kilogram (W/kg). The quantity expressed by these units is termed the specific absorption rate (SAR).

Formally defined, the SAR is the time rate at which radio-frequency electromagnetic energy is imparted to an element of mass of a biological body. The SAR is applicable to any tissue or organ of interest (that is, can be applied to any macroscopic element of mass) or, as utilized in ANSI C95.1-1982 [B1], is expressed as a whole-body average. Ideally, anatomical distributions of SARs would be used explicitly to formulate a guide in recognition that absorption of electromagnetic energy from even the most uniform field can result in highly variable anatomical depositions of energy. It has been established [B31, B34, B35] through thermographic analyses of models of rats and man, and cadavers of rabbits, that

NCRP REPORT No. 86

BIOLOGICAL EFFECTS AND EXPOSURE CRITERIA FOR RADIOFREQUENCY ELECTROMAGNETIC FIELDS

NCRP

National Council on Radiation Protection and Measurements

Library of Congress Cataloging-in-Publication Data

National Council on Radiation Protection and Measurements.

Biological effects and exposure criteria for radiofrequency electromagnetic fields.

(NCRP) report ; no. 86)
"Issued April 15, 1986.
Bibliography: p.
Includes index.
1. Electromagnetism—Physiological effect. 2. Electromagnetism—Toxicology. 3. Radio waves—Physiological effect. 4. Radio waves—Toxicology. I. Title. II. Series.

QP82.2.E43N38 1986 612'.01442 86-2451
ISBN 0-913392-80-4

Preface

This report is the second of a series concerning radiofrequency electromagnetic (RFEM) radiation that constitutes an extension of the NCRP interest into the subject of non-ionizing radiation. The first report, NCRP Report No. 67, *Radiofrequency Electromagnetic Fields—Properties, Quantities and Units, Biophysical Interaction, and Measurements,* was published in 1981. The report provided a comprehensive discussion of fundamentals, especially those that relate to radiation protection. It provided the basis for future reports, including this one.

Soon after the work on Report No. 67 was begun, the NCRP formed Scientific Committee 53 to prepare a report on the biological effects of RFEM radiation. This scientific committee was also requested to consider the development of recommendations for exposure criteria if the committee felt that such recommendations could be justified on the basis of the adequacy of the biological information. The scientific literature on the biological effects of RFEM radiation is voluminous but of varying scientific quality, and it has taken considerable time to assess it. On the basis of a detailed evaluation, which is reflected in this report, the committee concluded that exposure criteria could be developed in spite of the limitations of the biological information and these too are included in this document.

It needs to be recognized that our understanding of the biological effects of RFEM radiation is still evolving, based on continuing research on this important subject. As a result, it is to be expected that the exposure criteria set out in this report will be evaluated periodically in the future, and possibly revised as new information becomes available. This is a continuing challenge for those involved in radiation protection and one to which the NCRP expects to respond.

This report was prepared by Scientific Committee 53 on Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Radiation. Serving on the Committee were:

Dr. Arthur W. Guy, *Chairman*
Bioelectromagnetics Research Laboratory
University Hospital
University of Washington
Seattle, Washington

Members

Dr. W. Ross Adey
Veterans Administration Hospital
Loma Linda, California

Dr. Don R. Justesen
Behavioral Radiology Laboratories
Veterans Administration Medical Center
Kansas City, Missouri

Dr. Edward L. Alpen
Donner Laboratory
University of California, Berkeley
Berkeley, California

Dr. Mary Ellen O'Connor
Department of Psychology
University of Tulsa
Tulsa, Oklahoma

Dr. Richard D. Phillips
Experimental Biology Division
Health Effects Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina

Advisory Members

Dr. Eleanor R. Adair
John B. Pierce Foundation Laboratory
New Haven, Connecticut

Dr. Sol M. Michaelson
Department of Radiation Biology and Biophysics
University of Rochester School of Medicine
Rochester, New York

Mr. Edward L. Hunt
Department of Microwave Research
Walter Reed Army Institute for Research
Washington, D.C.

Dr. Harvey A. Ragan
Biology Department
Battelle, Pacific Northwest Laboratories
Richland, Washington

Dr. Charlotte Silverman
Division of Biological Effects
Center for Devices and Radiological Health
Rockville, Maryland

Consultants

Dr. Chung-Kwang Chou
Division of Radiation Oncology
City of Hope Medical Center
Duarte, California

Dr. Richard H. Lovely
Biology Department
Battelle, Pacific Northwest Laboratories
Richland, Washington

Dr. Justus F. Lehmann
Department of Rehabilitation Medicine
University Hospital
University of Washington
Seattle, Washington

Dr. Jan A. J. Stolwijk
Department of Epidemiology and Public Health
Yale University School of Medicine
New Haven, Connecticut

Dr. W. A. Geoffrey Voss
Dental Pharmacy Building
The University of Alberta
Edmonton, Alberta, Canada

NCRP Secretariat—Constantine J. Maletskos

The Council wishes to express its appreciation to the Committee members, advisors and consultants for the time and effort devoted to the preparation of this report.

Especial thanks are due to Don R. Justesen for the contribution of his knowledge and significant time and effort to the editing of the scientific aspects of this report.

Warren K. Sinclair
President

Bethesda, Maryland
January 13, 1986

1. Introduction

The radio-frequency electromagnetic (RFEM) spectrum (Table 1.1) is formally defined as waves that range in frequency from >0 to 3×10^{12} Hz (Sams, 1968; ITU, 1981). This report addresses the biological effects of exposure to RFEM fields that range in frequency from 3×10^{6} to 10^{11} Hz and in *in-vacuo* wavelength from, respectively, 1000 to 0.003 meters. Included in this range are all shortwave and most microwave frequencies. Waves longer than 1000 m have scattering and absorption properties with respect to the human body that differ greatly from those of waves that approximate the body's physical dimensions; such waves should and will receive independent analysis by other assemblies of experts. RFEM fields that lie near the upper limit of the microwave spectrum (3×10^{11} Hz), and fields of even higher frequency in the sub-millimeter spectrum (3×10^{11} to 3×10^{12} Hz), i.e., fields at wavelengths that range from 3 mm to 300 μm, have received relatively little study in the biological laboratory and are not addressed in this report. However, exposure to far-infrared radiations, which overlap the RFEM spectrum and are defined as wavelengths from 300 to 20 μm (frequencies from 10^{12} to 1.5×10^{13} Hz), has been studied extensively in the laboratory and is covered by separate exposure criteria, at least in the industrial sector.

The lack of quantitative data on the biological effects of RFEM fields has resulted in widespread concern that such exposure poses the risk of injury to health regardless of intensity. Although there are several thousands of reports—scientific papers, books, articles, and newspaper accounts—of widely varying scientific quality that present data or opinion on the biological response to RFEM radiations, no consensus has emerged regarding thresholds and mechanisms of injury at specific absorption rates (*SARs*) below a few watts per kilogram (W/kg). The wide variation in RFEM-radiation exposure criteria around the world reflects this absence of consensus. An objective analysis of the scientific literature and recommendations for exposure limits by a qualified and unbiased group of experts is sorely needed.

To address this need, the National Council on Radiation Protection and Measurements (NCRP) decided in 1973 to extend its scope of activities to the publication of reports that provide evaluations of the biological effects of non-ionizing radiations and to the publication of

TABLE 1.1—*Frequency bands of the RFEM spectrum*[a]

Band number	Frequency range	Metric subdivision (waves)	Adjectival description	Acronym
1	>0 to 30 Hz	—	Sub-extremely[b] low frequency	SELF[b]
2	30 to 300 Hz	Megametric	Extremely low frequency	ELF
3	0.3 to 3 kHz	—	Voice frequency	VF
4	3 to 30 kHz	Myriametric	Very-low frequency	VLF
5	30 to 300 kHz	Kilometric	Low frequency	LF
6	0.3 to 3 MHz	Hectometric	Medium frequency	MF
7	3 to 30 MHz	Decametric	High frequency	HF
8	30 to 300 MHz	Metric	Very-high frequency	VHF
9	0.3 to 3 GHz	Decimetric	Ultra-high frequency	UHF
10	3 to 30 GHz	Centimetric	Super-high frequency	SHF
11	30 to 300 GHz	Millimetric	Extremely high frequency	EHF
12	0.3 to 3 THz	Decimillimetric	Supra-extremely high frequency[c]	SEHF

[a] From Sams (1968), based on international treaty involving participants in the International Telecommunications Union (ITU, 1981).

[b] Band 1 is a designated band with no official adjectival description and symbol. Suggested entries are shown for this band.

[c] Band 12 has no official adjectival description. A suggested entry is shown for this band.

recommendations aimed at limiting exposures. Because there was very little standardization of quantities and units relating to this field, and because there was considerable confusion between ionizing and non-ionizing radiation, the NCRP felt that, as a prerequisite to the report on biological effects and exposure criteria, a publication was needed on properties, quantities, units, biophysical interactions, and measurements relating to RFEM fields. This first report, NCRP Report No. 67, published in March 1981 (NCRP, 1981), provides a background on the physical parameters and mechanisms of interaction of RFEM fields with matter, a background essential for the interpretation and understanding of the present report. The complexity of the interaction of these fields with biological systems makes it difficult to interpret the large volume of literature on the subject, because a substantial fraction of the research reported in the literature lacks the essential quantitation discussed in NCRP Report No. 67. The biological effects of exposure to RFEM fields depend on many factors that complicate

the interpretation of the literature and the specification of appropriate exposure limits.

Unlike ionizing radiation, RFEM radiation must be specified in terms of carrier frequency, modulation, electric-field and magnetic-field strengths (or power density when applicable), and zone of irradiation (near or far field). Also complicating the task of recommending exposure guides is the fact that unrestricted exposure of the body to a plane-wave or a multipath field at a given intensity can have results far different from those of partial-body exposure at the same intensity. Unlike ionizing radiation, the spatially averaged field strength, depending on the volume of space over which the fields are averaged, may vary for a given body from practically zero to levels far exceeding any proposed limit on exposure. This wide variation of field strengths necessitates the use of exclusion clauses in the specified exposure criteria, as discussed in Section 17.

This report, which begins with a discussion of fundamental studies at the molecular level in Section 2, presents a review of the subject matter covered in NCRP Report No. 67 on mechanisms of interaction of RFEM fields with tissue. The discussion continues to progressively larger scales of interaction, beginning with macromolecular and cellular effects in Section 3, chromosomal and mutagenic effects in Section 4, and carcinogenic effects in Section 5. The scope of the subject matter is then expanded to include systemic effects such as those on reproduction, growth, and development in Section 6, hematopoiesis and immunology in Section 7, endocrinology and autonomic nervous function in Section 8, cardiovascular effects in Section 9 and cerebrovascular effects in Section 10. The discussion in Section 10 places strong emphasis on the blood-brain barrier, which has received considerable attention in recent years.

Another controversial area based on many conflicting reports—the interaction of electromagnetic fields with the central nervous system and special senses—is discussed in Section 11. Some of the more interesting and controversial effects that have received widespread attention, such as frequency and intensity "windows," are discussed. Section 11 concludes with a discussion of neurological effects, which include the peripheral neuromuscular system. Some of the more sensitive biological end points, those associated with behavior, are discussed in Section 12; these end points contrast greatly with the apparently insensitive biological endpoint of cataractogenesis discussed in Section 13. In Section 12, a thermoelastically mediated interaction, which has received widespread attention over the past decade, is discussed as an auditory neural effect, and it is a phenomenon that deserves special attention. This interesting phenomenon would never have been clearly understood without the development of a quantitative argument based on the material presented in NCRP Report No. 67.

Probably of greatest importance in terms of the effects of RFEM radiations on human populations are the epidemiological studies discussed in Section 14. Thermoregulation is discussed in Section 15 and is an especially important subject because irradiation of an organism can result in hyperthermia, which is responsible for many reported effects. Hyperthermia, as such, is also extremely important because it is the basis for the use of shortwave or microwave radiation as an adjunct to the treatment of cancer, as reviewed in detail in Section 16.

Because the major purpose of this report is to interpret the literature in terms of health and safety of human beings in an RFEM environment, the human exposure criteria and rationale provided in Section 17 contain significant conlusions. It was necessary to make difficult decisions in arriving at these conclusions. Because the biological data base is drawn from reports varying in quality from poor to excellent, one must be aware that the data forming the basis of this chapter also vary in quality. Thus, value judgments had to be made concerning the data base discussed in the preceding chapters. Also, practical problems that relate highly localized exposures of the body to low-power radio devices essential to the quality of life and to public safety had to be dealt with by recommending maximal energy-absorption levels in addition to exposure levels.

The history of therapeutic applications of RFEM fields, which is reviewed in Section 16, is important because it covers a period when large numbers of human beings were exposed to highly intense RFEM fields. The history is also illuminating, in relation to today's controversies, in that it points out how misconceptions, that still exist today, were recognized early.

The cutoff date for the literature review of this report is the end of 1982. A few references have 1983 dates. These references were originally abstracts dated 1982 or earlier, but, because the references became available in early 1983 as peer-reviewed reports, these have been included as preferable to the abstracts when it has been possible to do so. Section 17.6, "Considerations possibly influencing the criteria in the future," is included in order to alert the reader about these new developments. References to this subsection are, of course, current references for the period 1983 to 1985.

2. Mechanisms

2.1 Introduction

Interpretation of mechanisms of biological effects of RFEM fields is clouded by a host of conflicting reports and opinions, especially when incident fields are at intensities that fail discernibly to elevate the temperature of the *in-vivo* or *in-vitro* preparation. Even when fields are at intensities associated with reliable elevations of the temperature of the preparation, the possibility that observed effects are due in part to field-specific events cannot be excluded. *Direct* interactions by electric and magnetic fields with biological materials not only are possible but are demonstrable, both *in vitro* and *in vivo* (*cf.* e.g., Saito and Schwan, 1961; Presman, 1970; Walcott *et al.*, 1979).

There is an inherent difficulty in distinguishing and discriminating between thermal and athermal[1] effects, a difficulty borne both of a methodological problem and of faulty inference. When, for example, a complex organism exhibits a behavioral or physiological response to irradiation by an RFEM field, the phenomenological character of the response provides no definitive leverage on which mechanism of three possible classes is operative: thermal, athermal (field-specific), or the two in some combination. This threefold set of possibilities defines the methodological—some would say epistemological—problem. The issue of faulty inference is exemplified by the widely held view in the bioelectromagnetics community that biological responses to weak fields are *a priori* evidence of athermal causation. The hot tip of a small soldering iron that made accidental contact with the epidermis of an unsuspecting technician would result in a dramatic behavioral response. An outside observer equipped with even the most sensitive of thermometric or calorimetric devices would be unable to detect the average elevation of body temperature or the quantity of energy imparted by the brief contact—and if not aware of the instrument of

[1] An athermal effect, referred to as a "field-specific" effect, is an effect not attributable to changes of temperature when RFEM energy is imposed on or absorbed by a medium or system. The term "athermal" is to be preferred over that of "non-thermal". On the basis of newer knowledge, the above definition supersedes that in NCRP Report No. 67 (NCRP, 1981) where this effect is described as a non-thermal effect and is defined as a change in a medium or system that is not directly associated with heat production when electromagnetic energy is absorbed.

stimulation, would doubtless interpret the response as an athermally inspired event. This is not to argue that all "weak-field" responses are provoked by thermal "hot spots"—although some so-called weak-field effects are probably of thermal-hot-spot origin—only that the strength of the incident field has no *a priori* bearing on the question of mechanisms.

An ideal methodology in elucidating mechanisms of interaction is one in which independently detectable thermal and field-specific responses are elicited from the same biological system by the same field. Although this ideal has not been fully realized, Pickard and colleagues have articulated testable theory, have developed novel techniques, and have performed innovative experimentation that collectively exemplify the ideal approach (see, e.g., Pickard and Rosenbaum, 1978; Pickard and Barsoum, 1981; Barsoum and Pickard, 1982a, b).

The biological specimens selected by Pickard and colleagues are algae of the characean family, primitive plants with membranes that exhibit excitability, action potentials, and graded responses to mechanical or electrical stimulation (*cf.* Pickard, 1973; Pickard and Barsoum, 1978). A single, elongate cell is maintained in a circulating fluid medium in a holding device so constructed that part of the cell can be exposed to an RFEM field while a distal part, not exposed, is contacted by electrical recording electrodes. A burst of CW RFEM energy at frequencies ranging from tens of kilohertz to tens of gigahertz has been found to elicit a relatively prolonged electrical response of ostensibly thermal origin, one that persists for some seconds after a burst of radiation is absorbed. An earlier response, an offset of the membrane's resting potential that occurs within a few milliseconds, is a field-specific potential that is elicited by the burst of RFEM energy, but only at carrier frequencies below 10 MHz (Pickard and Barsoum, 1981).

Ironically, the thermal basis of the prolonged response has not been unequivocally demonstrated, but the early offset potential is unarguably the result of non-linear—rectifying—properties of the characean membrane. The quantity of absorbed energy required to elicit the field-specific, offset response is relatively large, a requirement also in the earlier demonstration of pearl-chain formations by Saito and Schwan (1961). Were it not for the continuous cooling of the characean preparations by circulating fluids during periods of irradiation, the preparation would be rapidly denatured by marked elevations of temperature.

Although exemplifying an ideal experiment, the work on the characean organism is of unknown generality. The data are extremely

important, however, in revealing unequivocally that a field-specific effect can and does attend exposure of a biological preparation to an intense burst of CW RFEM radiation, at least at frequencies below 10 MHz, but these data shed little light on questions that attach to another class of athermal interactions, i.e., that observed after acute exposure to relatively very-low-intensity, sinusoidally modulated shortwave and microwave fields (*cf.*, e.g., Bawin *et al.* 1975; Blackman *et al.*, 1980; Adey, 1980). In experiments in which isolated chicken brains were exposed to CW fields or to fields modulated at 3 to 30 Hz, an exodus of calcium ions (Ca^{2+}) from brain materials was observed, but only to modulated fields within a narrow band of frequencies centered near 15 Hz—and only within a narrow range of power densities. Because the average amount of energy captured by brain materials was held constant across frequencies, thermal effects alone could not be responsible for the release of Ca^{2+}. These intriguing experiments are discussed in detail in Section 11.

As a point of departure in the discussion of mechanisms, it can be stated that there is ample evidence that athermal interactions in biological materials are not only possible but have been demonstrated for fields both strong and weak. It must also be stated that the biophysical mechanisms of these athermal events are but poorly understood. Summarized in this section are both data and theory that bear on thermal mechanisms and on the largely uncharted frontier of athermal interactions.

In addition to the discussion on mechanisms in this section, further discussion on mechanisms will be found in Section 11 on RFEM interactions with the nervous system. While this additional discussion could have been incorporated in this section, it has been kept in Section 11 to maintain continuity there.

2.2 Mechanisms of Interaction with Biological Materials

No one debates the potency of thermal effects of RFEM irradiation at high power densities ($\geq$100 mW/cm^2). Controversy arises, however, over interpretations of mechanisms at low power densities ($\leq$10 mW/cm^2) at which athermal biological effects have been demonstrated. Figure 2.1 summarizes data on dielectric dispersion, which have given rise to theories of interactions of RFEM fields with matter.

Schwan (1975, 1977) states that resonant interactions of biopolymers with electric fields are unlikely at frequencies below 100 GHz.

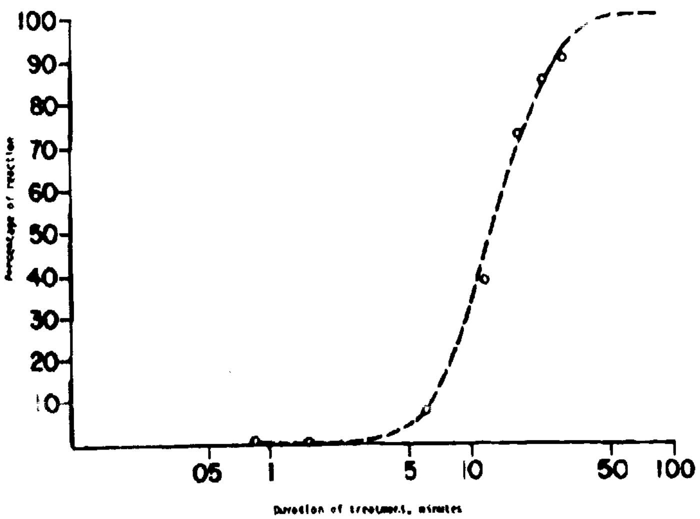

Fig. 16.6. Dependence (relative to maximal value) of hyperemia on duration of treatment. (From Lehmann, 1971.)

increased surface vasodilation, will prevent flow of thermal energy into the deeper musculature. No increase in the flow of blood to deeper tissues will result, and there may even be vasoconstriction to compensate for the increased flow of blood near the body's surface.

Nervous reflexes arising from surface heating of one part of the body can lead to temperature increases in other parts of the body, e.g., in an opposite extremity, but these ΔTs are less pronounced than the primary increases (Fischer and Solomon, 1965). Relaxation of striated skeletal muscles may occur, and muscle spasms may be resolved by surface heating because of reflexive nervous reactions from surface-temperature receptors. Thus, in general, surface heating provides only mild physiologic and therapeutic reactions, and any effects of the deeper pathologic conditions are only reflexively mediated.

Effective therapeutic heating of tissues below the skin, e.g., in the subcutaneous layer of fat, by RFEM fields requires proper selection of frequency, applicator, and input power so that the temperatures of the deeper tissue can be raised to the optimal level of 44 to 45 °C within a 5- to 15-min period. The duration of the maximal temperature can be controlled by adjusting the input power level. Just before or when the temperature reaches the maximal level, vasodilatation will produce a marked increase in blood flow that will limit the ΔT in tissues with good vascularity, which will be followed by a decrease in temperatures from the peak value by several degrees Celsius. An exposure period of 20 to 30 min is generally required to produce optimal therapeutic benefits.

17. Exposure Criteria and Rationale

17.1 Background

In the early to middle 1950s, tentative efforts were made to establish exposure criteria for RFEM fields to provide a margin of safety for industrial populations. The data base needed to establish exposure criteria and limits was almost non-existent from a biological point of view, and only the preliminary, pioneering studies of energy absorption and transfer processes by Schwan and students had been reported (*cf.*, e.g., Schwan and Piersol, 1954, 1955; Schwan and Li, 1953, 1956). Because the evidence at that time supported the position that hazards would arise only from heating of tissues by absorption of RFEM energy, the general approach was to establish an exposure criterion based on tolerable thermal loading. Participants in the first Tri-Service Conference on the Biological Hazards of Microwave Radiation (Pattishell, 1975) formally accepted for the first time a limit on occupational exposure: a maximal power density of 10 mW/cm², which was applicable to military personnel at all "microwave frequencies." Several private corporations also established working limits on exposure as operating guidelines, but it was not until 1966 that Committee C95.1 of the American National Standards Institute (ANSI) established a working subcommittee (Subcommittee C95-IV) to develop exposure criteria. The limit proposed by this subcommittee was the same as that prepared by the Tri-Service Committee in 1957 (a power density of 10 mW/cm² at frequencies from 10 MHz to 100 GHz). In 1974, this standard was retained unchanged, except for minor revision, by the C95.1 committee. In 1982, ANSI promulgated a new revision that incorporated recognition of substantial frequency-dependent variations in rates of energy transfer to the human body from an RFEM field (ANSI C95.1-1982). The limits of the new standard, which are summarized in Table 17.1, explicitly account for these variations.

ANSI standards are advisory only. The Occupational Safety and Health Administration adopted the 1966 ANSI-C95.1 standard as an exposure guide in the workplace (OSHA, 1971). However, in the application of the OSHA regulations, two rulings by the OSHA Review Commission, an independent agency, (1) that standards based on

TABLE 17.1—*ANSI C95.1-1982 protection guides: radiofrequency electromagnetic radiation*[a,b]

Frequency (f) range	Equivalent power density[c]	(Electric field)[2]	(Magnetic field)[2]
MHz	mW/cm²	V²/m²	A²/m²
0.3–3	100	4×10^5	2.5
3.0–30	$900/f^2$	$4 \times 10^3\ (900/f^2)$	$0.025(900/f^2)$
30–300	1.0	4×10^3	0.025
300–1500	$f/300$	$4 \times 10^3\ (f/300)$	$0.025(f/300)$
1500–100,000	5.0	2×10^4	0.125

[a] From ANSI (1982).

[b] measured 5 cm or greater from any object in the field and averaged for any 0.1 h (6 min).

[c] (Electric Field)²/1200π or 12π(magnetic field)², whichever is greater.

"*should*" statements, which the regulations are, are not enforceable because they are advisory, and (2) that a hazard addressed by an advisory standard cannot be the subject of a general duty citation, as attempted by OSHA to counteract the effect of the first ruling, resulted in the inability of OSHA to implement and enforce its non-ionizing regulations. In a 1982 Field Directive, OSHA affirmed, among other matters, that these decisions of the OSHA Review Commission are its current policy.

In 1975, the United States Air Force published a two-step frequency-dependent standard, AFR 161-42, that specified permissible exposure levels of 50 mW/cm² at frequencies between 10 kHz and 10 MHz, and 10 mW/cm² at frequencies between 10 MHz and 300 GHz (USAF, 1975).

It is beyond the scope of this report to provide a complete coverage of proposed and current exposure criteria for countries other than the United States. As in other Western nations, these values range from limits quite close to those recommended in the ANSI-1974 standard (e.g., 10 mW/cm² in the Federal Republic of Germany, in the United Kingdom, and in the Netherlands), to values similar to the more recent Swedish and Canadian standards (~1 mW/cm²). Among the Eastern European countries, the working levels for occupational exposure are significantly lower than those of any ANSI standard. These standards are reviewed in a document published by the World Health Organization (WHO, 1981). In summary, this document classifies Eastern European standards in two groups. Group I is represented by the standard of the Union of Soviet Socialist Republics, which specifies a working-day limit of 10 μW/cm², which can be increased to 1 mW/cm² for periods not exceeding a few minutes. The WHO Group-

II standards include those of the German Democratic Republic, Poland, and Czechoslovakia. These countries have general-population, continuous-exposure guides ranging from 10 to 100 μW/cm².

Clearly, varied opinion and philosophy underlies these widely ranging standards for exposure to RFEM fields. It is also clear that, until the promulgation of the ANSI-1982 standard, little consideration had been given by standard setting bodies in the United States to the role of the carrier frequency of the radiating source in relation to the deposition of energy within the body, and, hence, to a more accurate assessment of biological effectiveness of the radiation.

17.2 Measurement and Units for RFEM Fields

The transfer of energy from the radiation field of an RFEM source to a biological system, and the ultimate fate of that transferred energy in terms of biological change in living tissue, is an extremely complex problem. The details of field-body interactions have been presented at length in a publication by NCRP Scientific Committee 39, Report No. 67, which is entitled *Radiofrequency Electromagnetic Fields: Properties, Quantities and Units, Biophysical Interaction and Measurements* (NCRP, 1981). Report No. 67 is a primary source on which the present report is based with respect to determination of exposure guidance. Indeed, it was also the basis upon which the ANSI standard was developed.

17.2.1 *Power Density and Field Strengths*

NCRP Report No. 67 reviews the various means of measuring RFEM fields and emphasizes that there is little possibility of directly measuring the absorption of energy by biological bodies at the cellular level. It is necessary to measure some characteristic of the incident field, and from this to impute an energy deposition rate in the tissue of interest. From the earlier portions of this section, it is evident that all previous exposure criteria have characterized the field in units of the power density of an equivalent far-field plane wave (in, e.g., mW/cm² or W/m²). In some cases, measurements of the electric-field strength in V/m and/or of the magnetic-field strength in A/m have also been used as exposure criteria (see Table 17.1). Because nearly all devices available to measure radiation fields fundamentally measure the strength of the electric or the magnetic field, there is much to be said for specifying exposure limits in these terms. The relation between the power density of a far-field plane wave and the strength of its fields is simple:

$$S = E^2/1200\pi = 12\pi H^2, \tag{17.1}$$

where power density, S, is expressed in $\mathrm{mW/cm^2}$, electric field strength, E, is expressed in V/m, and magnetic field strength, H, is expressed in A/m.

17.2.2 *Dosimetry*

Although the frequency-dependent rate of RFEM energy absorption by a biological body was not formally incorporated into exposure guidelines until the advent of ANSI-1982 standard, this dependency was discovered in the early 1960s by a Soviet scientist, V. A. Franke (*cf.* Franke, 1961; Presman, 1970), who exposed models of human beings to fields that simulated longwave, shortwave, and microwave irradiation in the far field. These experiments were later confirmed and extended by Gandhi and colleagues (*cf.*, e.g., Gandhi, 1974, 1975b, 1980b; Gandhi *et al.*, 1977; Durney *et al.*, 1978; Gandhi *et al.*, 1979), who performed analytical and experimental studies on models of human beings in conjunction with experimental studies of small animals. The primary factors that control rate of energy absorption were found to be the wavelength of the incident field in relation to the dimensions and geometry of the irradiated organism, the orientation of the organism in relation to the polarity of field vectors, the presence of reflecting surfaces, and whether conductive contact is made by the organism with a ground plane. The maximal rate of energy absorption from a plane wave by the isolated, ungrounded mammal was found to occur when its long axis is parallel to the vector of the electric field and its axial length approximates four tenths of the wavelength of the incident field. Under these conditions, the organism exhibits *resonance*, and its electromagnetic capture surface is larger by 2- to 3-fold than is the area of its geometric cross section. The biological body, therefore, conforms to predictions of antenna theory (Gandhi, 1974). In addition, if the resonant target is electrically grounded—which roughly halves the resonant frequency—or if other reflective surfaces or objects are in proximity, the rate of energy absorption can increase to even higher levels.

In the wake of the pioneering investigations of Franke and Gandhi, it came as no surprise when a sizeable number of studies of murine and primate animals revealed that rates of energy absorption are more reliable predictors of biological effects than are power densities of the

incident field (see, e.g., Section 12). That measures of absorbed energy are a prerequisite to valid scaling of strengths of incident fields at different frequencies for predicting biological responses was recognized early by the clinicians (Mittlemann *et al.*, 1941; see also Section 16), but it was not until the late 1960s that a dosimetric approach to control of RFEM radiations, comparable to that used in the fields of clinical pharmacology and ionizing radiation, was introduced (Justesen and King, 1970; Justesen *et al.*, 1971; King *et al.*, 1971; Johnson, 1975; Justesen, 1975; NCRP, 1981; Guy, 1983). The mass-normalized time rate of energy absorption (dose rate) and its time integral (energy dose), as respectively specified in SI units of W/kg and J/kg, were adopted by the NCRP, and are described in detail in NCRP Report No. 67 (NCRP, 1981). The RFEM-energy dose was labeled *Specific Absorption* (*SA*), and the dose rate was labeled *Specific Absorption Rate (SAR)*. This nomenclature, which is specifically applicable to dosimetric measures of RFEM fields, was devised by NCRP as a more suitable terminology than the generic terms of *dose* and *dose rate*, which carry for many individuals connotations of ionizing radiation.

The *SAR* is defined as the time (t) derivative of incremental energy ($\mathrm{d}W$) absorbed by an incremental mass ($\mathrm{d}m$) contained in a volume element ($\mathrm{d}V$) of a given density (ρ):

$$SAR = \frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\mathrm{d}W}{\mathrm{d}m}\right) = \frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\mathrm{d}W}{\rho \mathrm{d}V}\right). \tag{17.2}$$

The *SA* is the time integral of the *SAR*. NCRP Report No. 67 discusses the *SAR* in detail and presents a comprehensive review of the physical theory that underlies it.

17.2.2.1 *Whole-Body Dosimetry.* The *SAR*, as utilized in the ANSI-1982 standard and in the present report is based, unless otherwise noted, on the whole-body mass of the irradiated organism. The *SA* values are similarly based and are implied, if not made explicit, by the 6-min period that is adopted for averaging the limiting *SAR* for exposed workers. Thus, the limiting whole-body-averaged *SA* for any 6-min period of exposure is 144 J/kg for the *SAR* limit of 0.4 W/kg (Sections 17.3 and 17.4.1).

17.2.2.2 *Distributive Dosimetry.* The *SA* and *SAR* are as applicable to the mass of individual body parts as they are to the total mass of the organism, and, indeed, because rates of absorption of RFEM energy can differ radically within the volume of an organism, there is both clinical and experimental utility in determining *SA*s and *SAR*s in discrete organs or tissues of interest. Distributive dosimetry was pioneered by A. W. Guy (Guy, 1971b; Guy *et al.*, 1968, 1974), who used the thermographic camera in studies of biologically simulating models ("phantoms") and of cadavers of laboratory animals. This work revealed that the distribution of *SAR*s is a highly complex function of many variables: carrier frequency; zone of irradiation; field polarization; electrical properties of tissues; and mass, geometry, and momentary orientation of the biological target.

Because the distributions of absorbed energy across species, frequencies, and exposure environments are so highly variable, the whole-body-averaged *SAR*s and *SA*s have been adopted on practical grounds as the dosimetric measures of choice in regulatory practice and standard setting. Moreover, because ethical considerations dictate that whole-body dosimetric values must be estimated or extrapolated for living human beings, the primary guides in limiting human exposures to RFEM fields must be specified in electric and magnetic field strengths (or in power densities in the case of exposure in the far field of a plane wave). As such, the role of *SA*s and *SAR*s is that of *deriving* permissible field strengths or power densities of incident fields of differing carrier frequency. In those cases in which it has been established that there are highly intense, focal concentrations of absorbed RFEM energy in the body (i.e., electromagnetic "hot spots"), this knowledge should supersede the whole-body value and lead to a corresponding reduction in the permissible level of exposure.

17.2.2.3 *Caveats on Interpretation of Dosimetric Measures.* Neither the strength of the incident field nor the quantity of energy absorbed from it by an organism has any *a-priori* warrant in the interpretation of causal mechanisms. There has been an unfortunate proclivity by some investigators to assume that the *SAR* and the rate of tissue heating are physical identities. Although the consequence of the Second Law of Thermodynamics is that the *ultimate* fate of absorbed RFEM energy is thermalization of tissues, transient field-specific effects have also been observed. A response by an organism to RFEM radiation may have a thermal basis, an athermal basis, or a combined basis. Determination of which of these three classes of causation is operative in a given context rests upon appropriate experimentation and inference, not on presumption.

The *SAR* is a practical tool by which one can make allowances for the complex absorbing and scattering properties of organisms as exemplified by the large frequency-dependent variations in quantities of energy absorbed from a field at a constant power density. Figure 17.1 (composite from Gandhi, 1979; Guy *et al.*, 1978, 1983, abstract; Lin *et al.*, 1977; Chou and Guy, 1982) shows frequency-dependent *SAR* curves of several prolate spheroids at a power density of 10 mW/cm^2 in the far field of a plane wave. These curves also demonstrate the

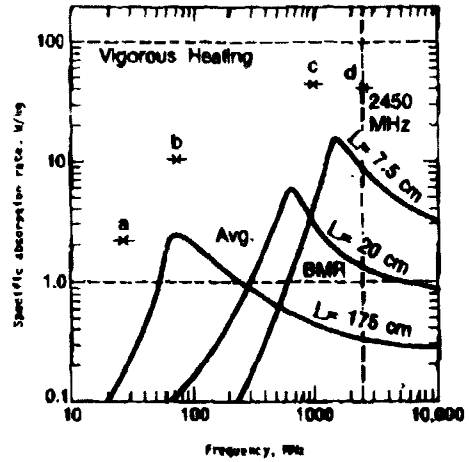

Fig. 17.1. Average *SAR* measured in prolate spheroids of various lengths, *L*, for an exposure to a power density at 10 mW/cm^2 at various frequencies. These models are used to simulate exposure of various experimental subjects in RFEM fields (after Gandhi, 1979). The points identified by the letters a, b, c and d indicate maximal localized *SAR* levels based on measurements as follows: a and b, in models of human beings (Guy *et al.*, 1978, 1983); c, in rats (Lin *et al.*, 1977); and d, in mice (Chou and Guy, 1982.) The average basal metabolic rate (BMR) is shown by the lower dashed horizontal line.

extreme differences in "worst-case" whole-body-averaged rates of energy deposition as a function of body dimensions. Given a length of 7.5 cm for the prolate spheroidal model of a 25-g mouse, the maximal *SAR* (~12 W/kg) occurs near 1500 MHz. For the model of standard man, a 175-cm prolate spheroid, the maximal *SAR* (~2 W/kg) occurs at approximately 70 MHz.

For the purpose of establishing exposure criteria in the following sections, the *SAR* is a fundamental quantity. There is, however, no intent to define exposure criteria solely in terms of *SAR*. Consideration is also given to other factors where appropriate. These factors include the possibility of severe deviation from uniformity of energy deposition, especially at the spectral extremes of frequency, as well as possible modulation- and carrier-frequency-specific biological responses.

17.3 Development of the SAR Exposure Criterion

As discussed earlier in this section, the absorption and distribution of RFEM energy result in an extremely complex phenomenology that is dependent on a body's mass and shape, its orientation with respect to field vectors, its electrical properties, and the electrical properties of the exposure environment. Because of the multiplicity of interacting factors, exposure criteria must be established in a manner such that allowance is made for maximal amplification of biological effects as a result of field-object interactions. Furthermore, the criteria should take into account possible effects arising from unusual circumstances in either the external environment of the individual (e.g., ambient temperature and humidity) or the internal environment of the individual (e.g., hyperthermia, debility and disease).

The approach used by ANSI, in establishing exposure criteria that account for the frequency dependence of the *SAR*, has been chosen as appropriate to follow, with particular emphasis on examination of the domain of resonant frequencies of human beings from small infant to large adult. Special attention is therefore paid to the biological effects reported in the resonant-frequency region (30 to 300 MHz).

The body of scientific knowledge of biological effects of RFEM irradiation, although containing several thousands of archival reports, is fragmented: it is preponderantly based on acute exposures at relatively few frequencies. Ideally, exposure-control guidelines would also be based on a well-documented literature that reflects effects of chronic irradiation of a variety of species across a wide spectrum of frequencies. In spite of the shortcomings of the data, it is necessary to proceed prudently with the process of exposure control through the setting of standards, while exercising appropriate caution and fully informing the worker and the public of the limits of knowledge.

It would be inappropriate to repeat here an *in-extenso* review of data on RFEM radiations that have induced harmful effects in experimental animals, because the preceding sections have dealt with this subject exhaustively. It is essential, however, to summarize information on key end points that are useful in establishing exposure criteria.

The most important and directly useful data for the establishment of criteria for limiting exposure to any noxious environment are, of course, measurements and findings based directly on human beings. Unfortunately, data of this type, which are epidemiological or clinical in nature, are relatively few in number. The data that do exist have been reviewed in Sections 14 and 16.

In the absence of human data, it is necessary to turn to data on subhuman species in full realization that body dimensions and mass have an enormous controlling influence on the *SAR* at a given frequency. It is also necessary to realize that direct extrapolation of subhuman data to man is also fraught with problems because of specific anatomical, physiological, and biochemical differences among species.

In the frequency range of primary interest, i.e., 30 to 300 MHz, and also at higher frequencies in the microwave bands, a review of the

data of the previous sections indicates that behavioral disruption (Section 12) appears to be the most statistically significant end point that occurs at the lowest observed *SAR*.

The carrier frequencies associated with behavioral disruption range from 400 MHz to 5.8 GHz. These studies were performed on species ranging from laboratory rats to rhesus monkeys, and involved near-field, far-field, multipath, and plane-wave fields, both CW and modulated. In spite of marked differences in field parameters, thresholds of behavioral impairment were found within a relatively narrow range of whole-body-averaged *SARs* ranging from ~3 to ~9 W/kg. In contrast, the corresponding range of power densities is 8 to 140 mW/cm^2.

Thresholds of disruption of primate behavior were invariably above 3 to 4 W/kg, the latter of which has been taken in this report, as well as by ANSI, as the working threshold for untoward effects in human beings in the frequency range from 3 MHz to 100 GHz. It is clear that the laboratory-animal to human-being generalization over this wide spectrum should be modified in light of any evidence of increased susceptibility in specific frequency domains. (These specific domains are noted in Section 11 and are accounted for later in this section.) Having accepted a threshold of effect in terms of the whole-body-averaged *SAR*, one must apply an appropriate margin of safety. This safety margin has been taken as a factor of 10 for occupational populations, and the fundamental *SAR* exposure criterion of 0.4 W/kg is established for frequencies from 3 MHz to 100 GHz. The fundamental criterion arrived at in this report, a whole-body-averaged *SAR* of 0.4 W/kg averaged over any 6-min exposure period, does not differ from that chosen by ANSI. Here, however, this value is proposed as a limit only for occupationally exposed individuals, and new lower levels of averaged exposure are proposed for members of the general population.

17.4 Implementation of Exposure Criteria

17.4.1 *Occupational Exposure Criteria*

Because measurements of incident fields in the working environment will necessarily be made in terms of field strengths or in the more familiar units of power density, it is necessary to provide exposure criteria in these units. Furthermore, restatement of the exposure guidelines in terms of plane-wave-equivalent power densities allows a clear expression of the frequency dependence of the average *SAR*. For occupational exposures, this report proposes the adoption of a schedule of frequency-dependent power densities as shown in Figure 17.2. These do not differ from the schedule given by the ANSI protection guides in Table 17.1.

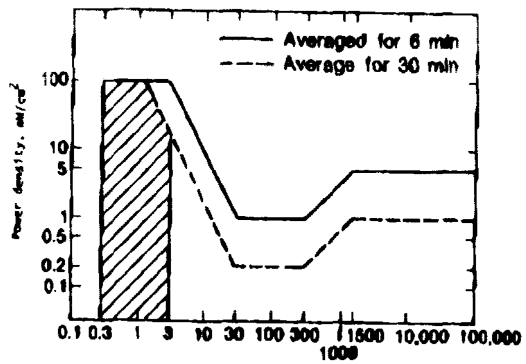

Fig. 17.2. Criteria for exposure to RFEM fields. Exposure, expressed in equivalent far-field power density (mW/cm²) for a whole-body averaged *SAR* of 0.4 W/kg, is shown in the solid line, taken to be the occupational exposure criterion. The dashed line, one-fifth that of the occupational criterion, is the criterion for the general population. Note the time-averaging period allowed for each criterion. The cross-hatched area represents a frequency range in which whole-body *SAR* has limited significance (see Section 17.4). The overall frequency range for the criteria is 0.3 MHz to 100 GHz. Depending on the circumstances, use of these criteria is constrained by a number of conditions (Sections 17.4.1 to 17.4.9) and the criteria cannot be applied without reference to these conditions.

At frequencies from 30 to 300 MHz, which is taken as the resonant-frequency domain for human beings from smallest child to tallest man, under both grounded and ungrounded conditions, the criteria are related to an equivalent far-field power density of 1 mW/cm², a value that limits the maximum whole-body averaged *SAR* to a level below 0.4 W/kg.

To limit the maximal whole-body averaged *SAR* to 0.4 W/kg beyond this range of frequencies (Figure 17.2), conversions are necessary, as follows:

1. At frequencies above 300 MHz, a transitional region is defined between 300 and 1500 MHz where the limiting power density for exposure is taken as the quotient of frequency in MHz divided by 300 ($f/300$). The resulting quotient expresses the power density in units of mW/cm².
2. At frequencies from 1500 MHz to 100 GHz, the power-density limit is 5 mW/cm².
3. At frequencies below 30 MHz and above 3 MHz, a transitional region is defined where the limiting power density for exposure is taken as the quotient of 900 divided by the square of the frequency in MHz ($900/f^2$). Again, the result of this calculation is expressed in units of mW/cm².

4. Below 3 MHz and above 0.3 MHz, the exposure criterion expressed in terms of power density is taken as 100 mW/cm², for reasons that are discussed later.

The rationale for the stated recommendations is that the resulting power density at any given frequency is roughly descriptive of the inverse of the resonance curve in Figure 17.1. At the two extremes of frequency, other considerations become important.

At frequencies below 3 MHz, energy deposition in the body decreases directly with the square of frequency (Figure 17.1), and the power density required to achieve a whole-body averaged *SAR* of 0.4 W/kg is very large indeed. At these frequencies, the physical and physiological effects of the ambient electric field will dominate. Because the effects of highly intense, low-frequency electric fields are associated with surface interactions, the average *SAR* at potentially harmful levels will fall to levels considerably below 0.4 W/kg. Figure 17.2 shows a cross-hatched area for frequencies below 3 MHz where the strength of the electric field is the limiting condition.

The recommended limits of exposure below 30 MHz, and perhaps at frequencies somewhat higher, apply to free-space exposure conditions, i.e., to conditions under which a person is not in contact with any object including the ground. In fact, the limits are also based on a person standing barefoot on the ground, this person having an unrealistic average conductance of a homogenized body. For other conditions, such as standing on the ground with insulation (e.g., shoes or wooden floor) and being grounded by contact of the hand with a grounded object (e.g., metal fence or pipe) or being grounded and touching an insulated metallic object (e.g., truck or crane), these limits should be lowered. For the first two conditions, the exposure limits must be determined with the use of three criteria: (1) whole-body average *SAR* (0.4 W/kg), (2) maximal local *SAR* (8 W/kg) (see Section 17.4.5), and (3) RF burns at point of contact (200 mA). Limits for the case of being grounded and touching an insulated metallic object can be determined with the use of the same three criteria but only on a case-by-case basis because the degree of hazard depends on the size of the object. (See Section 17.6 for possible future considerations influencing the criteria.)

17.4.1.1 *Pulsed or Continuous Wave (CW) Exposure, Time Averaging for the Occupationally Exposed.*

The biological data available for development of criteria were collected from a wide variety of radiation sources. In addition to varying frequency, the duty cycle of the generators also varied widely from CW to pulsed waves with large and small duty cycles. Because limited data are available to establish the relation between the biological effects of CW and pulsed sources, the decision has been made to continue the traditional usage of health-protection practices in controlling exposures to RFEM fields. This practice has been to average the power density over a period of 0.1 h (6 min), which serves to limit the mass-normalized quantity of energy imparted to the body to an *SA* of 144 J/kg. The same time-averaging period is recommended in the ANSI-1982 standard.

17.4.2 *General-Population Exposure Criteria*

Previous efforts to establish national and international exposure criteria have generally led to the publication of exposure guidelines that are designed for application to individuals who are occupationally exposed in a typical career pattern, i.e., 40 h per week and 50 weeks per year. The ANSI-1982 standard recommends the same limits of averaged exposure for the work place and for the general environment. Such a uniform approach is not traditional and, in keeping with NCRP's practice of differentiating between occupational and general populations, another set of criteria is recommended for the general public.

The reasons for a twofold set of criteria can be stated as follows. First, individuals exposed in the work place should be relatively well informed of the potential hazards associated with their occupation. Furthermore, these workers may have the opportunity to make personal decisions in regard to their exposure, based on the relative risk as they perceive it. Individuals subjected to RFEM radiation outside the work place are generally unaware of their exposure, and furthermore, if they are aware, they rarely have the option to reduce their level of exposure. Second, the population at large, some members of which could be exposed continuously to RFEM fields, contains subpopulations of debilitated or otherwise potentially vulnerable individuals for whom there is presently inadequate knowledge to set firm standards. For example, the sensitivity of aged individuals, of pregnant females and their concepti, of young infants, or of chronically ill persons is not known. Third, because the general population is much larger than the occupational population, there are more persons at risk, and, hence, the proportionate number of persons susceptible to potential harm can be greater unless exposure of the general population is kept at a lower level.

For the reasons given above, it is recommended that there be an averaged exposure criterion for the general public that is set at a level equal to one-fifth of that of occupationally exposed individuals. Therefore, the whole-body averaged *SAR* for the general public for continuous exposure should not exceed 0.08 W/kg. The rationale for the reduction by a factor of 5 is based on the exposure periods of the two populations, rounded off to one digit (40 work hours per week/168 hours per week = ~0.2). Implementation of this *SAR* in terms of power density is shown in Figure 17.2 as a dashed line. For reasons of prudence, considering the lack of knowledge of biological effects at low frequencies, it is recommended that, for frequencies below 3 MHz, the population exposure limit should continue to rise as shown, following the $900/f^2$ relationship. However, the line of this relationship intrudes into the frequency domain in which it is expected that hazards are associated with surface-acting electric fields and other factors may control the limits of exposure as described in Section 17.4.1.

17.4.3 *Time Averaging for the General Population*

The time base by which to average the limiting *SAR* for occupational exposure is 0.1 h (6 minutes). For exposure of the general population, an averaging period of 0.5 h (30 min) is recommended. The increased stringency of the general-population limit allows this liberalization with no significant additional risk because the population limit, along with the 30-min time-averaging period, restricts the maximal *SA* to the population during the 30-min period to a value of no larger than that experienced during the 6-min time-averaging period of occupational exposure. Overall, the *SA* for the population remains at one-fifth that of the occupational value. At the same time, the 30-min time-averaging period is responsive to some special circumstances for the public at large. Examples are transient passage by the individual past high-powered RFEM sources, and brief exposure to civil telecommunications systems.

17.4.4 *Special Circumstances for Population Exposure*

It is recognized that there are special circumstances in which the exposure limits for the general population may unnecessarily inhibit activities that are brief and non-repetitive. For example, the presence nearby of a number of emergency vehicles engaged in telecommunications might cause a brief exposure to fields at strengths above the general-population limit. Because only small groups of the population would be exposed under these conditions, and almost certainly not on a repeated basis, the occupational exposure levels are permitted for such cases.

17.4.5 *Localized Exposure Criteria*

Exposure limits for RFEM radiation for the human population are based to a great extent on data obtained from exposures of small animals to plane waves. Under such conditions, it is relatively easy to quantify the maximal rate of energy absorption by analytical or experimental means.

Although it is not practical to quantify distributions of absorbed energy, except for a few cases where special theoretical or laboratory techniques can be employed, it has been demonstrated frequently that the maximal localized *SAR* typically reaches levels as high as 10 to 20 times the whole-body averaged *SAR*. It has also been found in analyses of *SAR* distributions in models of human beings exposed to plane waves that maximal *SAR* levels, as is the case in exposure of the small animal, can reach 10 to 20 times the average value. It must then be recognized that, for exposure criteria based on whole-body-averaged *SAR*, such as those set out in this section, the maximal *SAR* in small regions of the body may be as much as 10 to 20 times higher (Figure 17.1).

The only practical way to cope with localized and non-uniform field exposures is to rely on the data base used to develop whole-body exposure limits. Then the bases for the criteria become quite simply that the general provisions for limiting exposure to a plane-wave field should not be violated: The occupational whole-body-averaged rate of energy absorption during localized exposure or exposure to non-uniform fields should not exceed 0.4 W/kg, and anatomically localized rates should not exceed those that are expected from a whole-body exposure to a plane wave that results in an average *SAR* of 0.4 W/kg.

The plane-wave exposure levels allowed by the limit for occupational exposure can be exceeded for a particular RFEM source, provided it can be shown that, for any individual that might be exposed to emissions from that source, the whole-body-averaged *SAR* does not exceed 0.4 W/kg and the local average *SAR* does not exceed 20 times the average, or 8 W/kg as averaged over a finite mass (one gram) of tissue over any period of 0.1 hour.

By the same argument, the criterion for general-population, localized exposure should allow no more than one-fifth the levels of *SAR* allowed for occupational exposures. However, in the case of individuals

in the general population who use radio emitters of various kinds (e.g., hand-held transceivers, remote control devices, etc.), the exposures of those individuals may be greater than the values recommended for the general population. Use of such devices is permitted, as a personal decision by the individual, provided that the devices are designed and used as designed so that the exposure of the individual does not exceed the recommended occupational guidelines and provided that, in using the devices, the individual does not expose other persons above the population guidelines.

It should be recognized that determination of whether a particular RFEM source will meet these criteria poses technical difficulties, and can be done only by a qualified person, a laboratory, or a scientific body for a general class of equipment. It is not possible to determine conformity to the special criterion by means of a power density measurement alone.

17.4.6 *Mixed-Frequency Fields*

Simultaneous exposure of a person to several sources of RFEM radiation (e.g., from commercial AM, FM, TV broadcasts) is the rule, each source radiating at a different frequency. Because the *SAR* indexes the exposure limit (Figure 17.2 expresses equivalent far-field power densities for a constant *SAR*), appropriately weighted power densities are needed to reflect a complex radiation environment. The combined power density that meets the criteria for mixed-frequency fields is recommended to be the sum of the power densities at each frequency:

$$S_T = S_1 + S_2 + S_3 + \ldots S_n, \tag{17.3}$$

where S_T is the combined power density, and S_1, S_2, S_3, and S_n are the power densities at the frequencies, f_i (i = 1,2,3,. . . n), of each RFEM source, with the condition that

$$\sum_{i=1}^{n} \frac{S_i}{L_i} = \frac{S_1}{L_1} + \frac{S_2}{L_2} + \frac{S_3}{L_3} + \ldots \frac{S_n}{L_n} \leq 1, \tag{17.4}$$

where the *Ls* are the exposure limits at the respective frequencies.

17.4.7 *Modulation*

Elsewhere in this report (Section 11), effects of RFEM fields under low-frequency modulation on *in-vitro* and *in-vivo* preparations have been discussed in detail. It is not known whether these effects pose a risk to health, but their reliability and their independent confirmation in avian and mammalian species dictate the need for caution. Therefore, a special circumstance exposure criterion has been provided as follows: If the carrier frequency is modulated at a depth of 50 percent or greater at frequencies between 3 and 100 Hz, the exposure criteria for the general population shall also apply to occupational exposures.

17.4.8 *Power-Density Peaks*

The time averaging of and the limits on power densities and *SARs* as provided in the criteria in this report preclude circumstances in which excessive instantaneous peak-power levels can occur. There is, therefore, no need to specify a limit on peak power, as such.

17.4.9 *Medical Use of RFEM Radiations*

The proposed exposure criteria are not applicable to medical applications of RFEM fields insofar as the patient is concerned, but are applicable to medical and technical staff that use RFEM sources in diagnostic and therapeutic procedures.

17.5 Measurements of RFEM Fields

Some exposure standards (e.g., ANSI-1982) specify that measurements of field strengths should be made at distances of 5 cm or more from any object to avoid errors incumbent with scattering properties of absorbing and reflecting objects in the RFEM field, and with practical limitations of measuring instruments. For example, objects immersed in an RFEM field at power densities below those specified in the beginning of Sections 17.4.1 and in Section 17.4.3 can produce a scattered field of apparent intensity greatly exceeding that of the primary source. Valid measurements of such scattered fields in proximity to an object are difficult or are not possible because of the finite size of the field sensor and because of the interaction of the field with the object. In addition, the quantity of RFEM energy that can be coupled from a scattered field to an exposed human being is small compared with that from a primary source. Although it is beyond the scope of this report to specify the measurement methodology needed to apply the exposure criteria and, until more detailed guidelines are available, it is recommended that measurements be made at a distance of 5 cm or more from any object in the field.

17.6 Considerations Possibly Influencing the Criteria in the Future

This document is based on literature references published up through the year of 1982. There are two new findings in the literature published after this date that could result in future changes in the RFEM criteria. One finding concerns the possibility of RF burns or excessively high, localized *SAR* occurring in the hands, wrists, or ankles of persons coming in contact with grounded metallic objects, and the other finding concerns a possible link between RFEM exposures and the increased incidence of malignant tumors. Details are discussed below.

17.6.1 *RF Burns and High Localized SAR*

Recent research on identifying hazards in the 10-kHz to 3-MHz frequency range based on measurements of body impedance and induced current in exposed, volunteer human subjects predicts that potentially hazardous levels of body current and localized *SAR* may occur for exposures within the recommended guidelines of this report at frequencies of 1 MHz or greater (Guy and Chou, 1982; Gandhi *et al.*, 1985; Guy and Chou, 1985). The threshold current for RF burns occurring on the finger due to contact with a conducting surface is 200 mA (Rogers, 1981), and the threshold *SAR* for vigorous and possibly damaging local heating based on diathermy treatments is 50 to 120 W/kg (Guy *et al.*, 1984). If the recommended standards based on the 10-kHz to 3-MHz studies are extrapolated to 30 MHz as shown in Figure 17.3, a maximum exposure level of 0.13 mW/cm^2 would have to be imposed to prevent RF burns and to prevent the maximal *SAR* from exceeding 8 W/kg for contact of the hand with any grounded conductor during exposure in an extended field. Because the quasi-static analysis used for the 10-kHz to 3-MHz range will become invalid with increasing frequency in the range 3 to 30 MHz and as the whole-body resonant frequency is approached, prediction of maximum permissible levels above 30 MHz would require more sophisticated models for grounded contact exposures than now available.

17.6.2 *RFEM Fields and Malignant Tumors*

A report (Kunz *et al.*, 1985) that was widely publicized in the news media as linking RFEM fields with cancer, indicated that 18 out of 100 Sprague-Dawley rats exposed for life under specific-pathogen-free

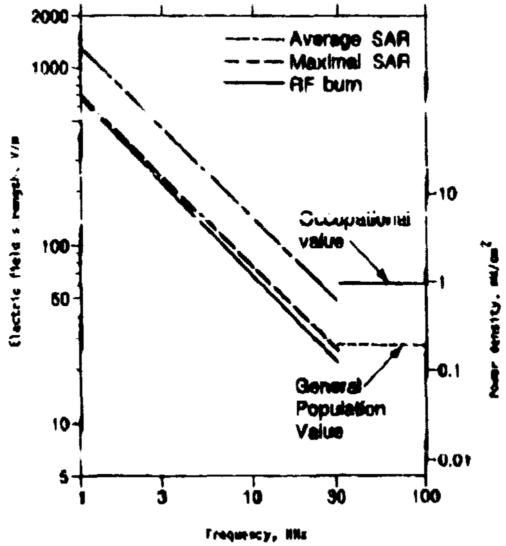

Fig. 17.3. Example of the exposure criteria in terms of electric field strength and power density based on not exceeding the average-*SAR* (0.4 W/kg), maximal-*SAR* (8 W/kg) and RF-burn (200 mA) criteria for whole-body exposure in an extended RFEM field of a person insulated from the ground (by the material on which the person is standing) but with a hand touching a grounded object (e.g., a metal fence). The extrapolation on the analysis of the data, obtained in the range between 10 kHz and 3 MHz, has been made up to 30 MHz, but it is not appropriate because present theory is not adequate to describe the interactions with the field as the frequency increases above 3 MHz and approaches the whole-body resonant frequency. In this example, the RF-burn condition becomes the limiting criterion and, at 30 MHz, it extrapolates to ~22 V/m or ~0.13 mW/cm². (Note that the two *SAR* curves are not parallel to the RF-burn curve because of the effect of increasing conductivity with frequency on the *SAR*.) (After Guy and Chou, 1982, 1986.)

(SPF) conditions to 2.45-GHz pulsed fields at *SAR* levels of 0.2 to 0.4 W/kg suffered from malignant neoplastic lesions. Only 5 out of 100 rats sham exposed under identical conditions suffered from the same lesions. The Mantel-Haenszel (M-H) analysis of the relative risk was 4.46 and the Chi-square test was 8.0 ($p = 0.005$, df = 1). The incidence of neoplastic lesions in either group is within the range of incidences reported for this strain of rat; only three tumors were present in rats younger than 12 months (all in the sham exposed), and the incidence rapidly increased after 18 months of age. The endocrine system has the highest incidence of neoplasia in the aging rats, as is to be expected in this experimental animal.

However, the authors state in the report: "The low incidence of neoplasia with no increase in any specific organ or tissue required the data to be collapsed and statistically evaluated with respect only to

occurrence of the neoplasm, with no attention given to the area of occurrence. This analysis indicated that neither group has an excess of benign lesions. There is statistical evidence that the mean number of primary malignancies was higher in the exposed animals than in the sham exposed, but the biological significance of this difference is reduced by several factors. First, detection of this difference required the collapsing of sparse data without regard for the specific type of malignancy or tissue of origin. Also, when the incidence of the specific primary malignancies in the exposed animals is compared with the specific tumor incidence reported in the literature, our exposed animals had an incidence similar to that of untreated control rats of the same strain, maintained under similar SPF conditions (Anver, Cohen, Lattuada and Foster, 1982). It is important to note that no single type of primary malignancy was enhanced in the exposed animals. From the standpoint of carcinogenesis, benign neoplasms have considerable significance under the assumption that the initiation process is similar for both benign and malignant tumors. The fact that treatment groups showed no difference in benign tumor incidence is an important element in defining the promotion and induction potential of microwave radiation for carcinogenesis. The collapsing of sparse data without regard for tissue origin is useful in detecting possible statistical trends, and the finding here of excess primary malignancies in the exposed animals is provocative; however, when this single finding is considered in the light of other parameters evaluated, it is questionable if the statistical difference reflects a true biological activity (Ward, 1983)."

The information in this subsection emphasizes that additional work in these important areas is required.

The NCRP

The National Council on Radiation Protection and Measurements is a nonprofit corporation chartered by Congress in 1964 to:

1. Collect, analyze, develop, and disseminate in the public interest information and recommendations about (a) protection against radiation and (b) radiation measurements, quantities, and units, particularly those concerned with radiation protection;
2. Provide a means by which organizations concerned with the scientific and related aspects of radiation protection and of radiation quantities, units, and measurements may cooperate for effective utilization of their combined resources, and to stimulate the work of such organizations;
3. Develop basic concepts about radiation quantities, units, and measurements, about the application of these concepts, and about radiation protection;
4. Cooperate with the International Commission on Radiological Protection, the International Commission on Radiation Units and Measurements, and other national and international organizations, governmental and private, concerned with radiation quantities, units, and measurements and with radiation protection.

The Council is the successor to the unincorporated association of scientists known as the National Committee on Radiation Protection and Measurements and was formed to carry on the work begun by the Committee.

The Council is made up of the members and the participants who serve on the eighty-two scientific committees of the Council. The scientific committees, composed of experts having detailed knowledge and competence in the particular area of the committee's interest, draft proposed recommendations. These are then submitted to the full membership of the Council for careful review and approval before being published.

The following comprise the current officers and membership of the Council:

Officers

President	Warren K. Sinclair
Vice President	S. James Adelstein
Secretary and Treasurer	W. Roger Ney
Assistant Secretary	Carl D. Hobelman
Assistant Treasurer	James F. Berg

Members

Seymour Abrahamson
S. James Adelstein
Roy E. Albert
Peter R. Almond
Edward L. Alpen
John A. Auxier
William J. Bair
John D. Boice, Jr.
Robert L. Brent
Antone Brooks
Thomas F. Budinger
Melvin W. Carter
George W. Casarett
Randall S. Caswell
Gerald D. Dodd
Patricia W. Durbin
Joe A. Elder
Mortimer M. Elkind
Thomas S. Ely
Edward R. Epp
Jacob I. Fabrikant
R. J. Michael Fry
Robert A. Goepp
Robert O. Gorson
Arthur W. Guy
Eric J. Hall
Naomi H. Harley
John W. Healy
William R. Hendee
John M. Hesley
Seymour Jablon
Donald G. Jacobs
A. Everette James, Jr.
Bernd Kahn
James G. Kereiakes
Charles E. Land
George R. Leopold
Ray D. Lloyd
Arthur C. Lucas
Charles W. Mays
Roger O. McClellan
James McLaughlin
Barbara J. McNeil
Thomas F. Meaney
Charles B. Meinhold
Mortimer L. Mendelsohn
William E. Mills
Dade W. Moeller
A. Alan Moghissi
Robert D. Moseley, Jr
Wesley Nyborg
Mary Ellen O'Connor
Frank L. Parker
Andrew K. Poznanski
Norman C. Rasmussen
William C. Reinig
Chester R. Richmond
James S. Robertson
Leonard A. Sagan
William J. Schull
Glenn E. Sheline
Roy E. Shore
Warren K. Sinclair
Lewis V. Spencer
John B. Storer
William L. Templeton
Roy C. Thompson
John E. Till
Arthur C. Upton
George L. Voelz
Edward W. Webster
George M. Wilkening
H. Rodney Withers

Honorary Members

Lauriston S. Taylor, *Honorary President*

Edgar C. Barnes
Victor P. Bond
Reynold F. Brown
Austin M. Brues
Frederick P. Cowan
James F. Crow
Merrill Eisenbud
Robley D. Evans
Richard F. Foster
Hymer L. Friedell
John H. Harley
Louis H. Hempelmann, Jr.
Paul C. Hodges
George V. LeRoy
Wilfrid B. Mann
Karl Z. Morgan
Robert J. Nelsen
Harald H. Rossi
William G. Russell
John H. Rust
Eugene L. Saenger
J. Newell Stannard
Harold O. Wyckoff

Currently, the following subgroups are actively engaged in formulating recommendations:

SC-1: Basic Radiation Protection Criteria
SC-3: Medical X-Ray, Electron Beam and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment Performance and Use)
SC-16: X-Ray Protection in Dental Offices
SC-18: Standards and Measurements of Radioactivity for Radiological Use
SC-28: Radiation Exposure from Consumer Products
SC-38: Waste Disposal
- Task Group on Krypton-85
- Task Group on Disposal of Accident Generated Waste Water
- Task Group on Disposal of Low-Level Waste
- Task Group on the Actinides
- Task Group on Xenon
- Task Group on Definitions of Radioactive Waste Levels

SC-40: Biological Aspects of Radiation Protection Criteria
- Task Group on Atomic Bomb Survivor Dosimetry
- Subgroup on Biological Aspects of Dosimetry of Atomic Bomb Survivors

SC-43: Natural Background Radiation
SC-44: Radiation Associated with Medical Examinations
SC-45: Radiation Received by Radiation Employees
SC-46: Operational Radiation Safety
- Task Group 1 on Warning and Access Control Systems
- Task Group 2 on Uranium Mining and Milling—Radiation Safety Programs
- Task Group 3 on ALARA for Occupationally Exposed Individuals in Clinical Radiology
- Task Group 4 on Calibration of Instrumentation
- Task Group 5 on Maintaining Radiation Protection Records
- Task Group 6 on Radiation Protection for Allied Health Personnel
- Task Group 7 on Emergency Planning

SC-47: Instrumentation for the Determination of Dose Equivalent
SC-48: Assessment of Exposure of the Population
SC-52: Conceptual Basis of Calculations of Dose Distributions
SC-53: Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Radiation
SC-54: Bioassay for Assessment of Control of Intake of Radionuclides
SC-57: Internal Emitter Standards
- Task Group 2 on Respiratory Tract Model
- Task Group 5 on Gastrointestinal Tract Models
- Task Group 6 on Bone Problems
- Task Group 8 on Leukemia Risk
- Task Group 9 on Lung Cancer Risk
- Task Group 10 on Liver Cancer Risk
- Task Group 11 on Genetic Risk
- Task Group 12 on Strontium
- Task Group 13 on Neptunium
- Task Group 14 on Placental Transfer
- Task Group 15 on Uranium

SC-59: Human Radiation Exposure Experience
SC-61: Radon Measurements
SC-63: Radiation Exposure Control in a Nuclear Emergency
SC-64: Radionuclides in the Environment
- Task Group 5 on Public Exposure from Nuclear Power
- Task Group 6 on Screening Models
- Task Group 7 on Contaminated Soil as a Source of Radiation Exposure
- Task Group 8 on Ocean Dumping

SC-65: Quality Assurance and Accuracy in Radiation Protection Measurements
SC-66: Biological Effects and Exposure Criteria for Ultrasound
SC-67: Biological Effects of Magnetic Fields
SC-68: Microprocessors in Dosimetry
SC-69: Efficacy of Radiographic Procedures
SC-70: Quality Assurance and Measurement in Diagnostic Radiology
SC-71: Radiation Exposure and Potentially Related Injury
SC-74: Radiation Received in the Decontamination of Nuclear Facilities
SC-75: Guidance on Radiation Received in Space Activities
SC-76: Effects of Radiation on the Embryo-Fetus
SC-77: Guidance on Occupational and Public Exposure Resulting from Diagnostic Nuclear Medicine Procedures
SC-78: Practical Guidance on the Evaluation of Human Exposures to Radiofrequency Radiation
SC-79: Extremely Low-Frequency Electric and Magnetic Fields
SC-80: Radiation Biology of the Skin (Beta-Ray Dosimetry)
SC-81: Assessment of Exposure from Therapy
SC-82: Control of Indoor Radon

Committee on Public Education
Study Group on Comparative Risk
- Task Group on Comparative Carcinogenicity of Pollutant Chemicals

Ad Hoc Group on Medical Evaluation of Radiation Workers
Ad Hoc Group on Video Display Terminals
Task Force on Occupational Exposure Levels

In recognition of its responsibility to facilitate and stimulate cooperation among organizations concerned with the scientific and related aspects of radiation protection and measurement, the Council has created a category of NCRP Collaborating Organizations. Organizations or groups of organizations that are national or international in scope and are concerned with scientific problems involving radiation quantities, units, measurements, and effects, or radiation protection may be admitted to collaborating status by the Council. The present